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형태 제약과 출입구를 고려한 설비 배치 및 복도 구조 디자인

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Factory Layout and Aisle Structure Design Considering Dimension Constraints and Door Locations

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The cut tree approach of Montreuil and Ratliff [16] and eigenvector approach [10] are used to automatically draw a feasible facility layout with aisle structure. The department arrangement can minimize an aisle distance criterion considering door locations and dimension constraints. The aisle distance is measured by the door to door distance between departments. An eigenvector and cut tree approaches [1] are implemented based on the branch and bound technique in Kim et al. [2] in order to obtain feasible layouts. Then, the algorithm to fix the door location of each department is developed. After the door locations are determined, the factory layout is evaluated in terms of aisle distance. The aisle structure is obtained by expanding the original layout. The solution is kept until we will find better factory layout. The proposed approach based on the branch and bound technique, in theory, will provide the optimal solution. If the runs are time and/or node limited, the proposed method is a strong heuristic. The technique is made further practical by the fact that the solution is constrained such that the rectangular shape dimensions length(l) and width(w) are fixed and a perfect fit is generated if a fit is possible.

Keywords : facility layout, aisle structure, branch and bound, door locations

1. INTRODUCTION

Because of an increasing interest in the flexible manufacturing systems (FMS), and computer integrated manufacturing systems (CIMS), the facility layout problem has obtained more attention in recent years. The objective of this paper is to generate a facility layout automatically (i.e., without a human's aid) with door locations and aisle structure. Since the facility layout problems are include in the class of NP-Complete problem [15], researchers have focused on the development of more efficient heuristic algorithms. When considering the determination of door locations, aisle structure and dimension constraints, the complex and unstructured nature of the factory layout problems in this paper has led little attention in the literature. Earlier attempts [7, 8, 14, 17, 20, 21] have focused on (1) determination of aisle structure given layout (2) determination of layout given aisle structure (3) determination of layout and aisle structure sequentially not simultaneously (4) without dimension constraints and determination of door locations.

This paper addresses the first attempt to obtain good factory layout considering the determination of door location, construction of aisle structure and dimension constraints, simultaneously. First, we will employ a branch and bound technique based on cut tree approach and eigenvector approach to obtain feasible factory layout because it presents a good initial layout visually.

The cut tree approach has three valuable characteristics (optimum separation, maximum flows and optimal aisle structure) for the layout problem [13, 16]. In order to strengthen its weakness (no specific procedure to change cut tree graph into a block layout [6]), eigenvector approach solution procedures for final layout will be provided and we will explain how the cut tree approach and eigenvector approach can be applied to feasible factory layout. The assumptions used in this paper are as follows :

(1) Width and length of each floor are given.
(2) From-to material flow chart for each department pair is given.
(3) The total number of departments is given.
(4) All departments have square or rectangular shapes which can not be distorted.

Using above the assumptions, methods for layouts of departments in the factory will be presented. Also, the aisle distance measure is employed to calculate the total cost. When aisle distance measure is used, we determine the location of each department's door and define distance between departments using the coordinates of door location and aisle structure.

2. LITERATURE REVIEW

CRAFT [4] is one of the most widely used facility layout technique because it considers material handling costs and provides heuristic solutions very quickly. The objective function in CRAFT is the minimization of the cost due to the flow of materials. With an interchanging approach, it tries to improve the layout (minimizing cost).

Drezner [10] presented an eigenvector approach to obtain a point layout when department size is a point. He provided a layout procedure for equal sized departments by separating the scattered points. The algorithm for point layout can be easily extended to the three dimensional facility layout problems. But, it is difficult to apply his algorithm to a problem with unequal department sizes and shape constraint (no distortion).

Tillinghast [19] combined the eigenvector approach and the quadratic assignment approach so as to obtain the final layout. When the position of any department is fixed, he used the eigenvector approach to obtain its candidate neighbors. Then, the branch and bound technique (he fixed several departments for corner positions and found departments for neighbors. see details in [2, 12]) is used for the final layout by enumerating all possible neighbors when department sizes are unequal but shapes are only squares. His algorithm efficiently and automatically creates a final layout based on fixed department size.

But, there is not a specific criterion to determine how many departments can be candidates for neighbors when optimality is not sought. He fixed a certain number, say k, and enlarges the circle until k departments are in the circle, where the center of circle is the point obtained by eigenvector approach. That means the procedure of clustering departments has no strong mathematical background (his general approach uses all departments are neighbors). Also, when he calculates the lower bound, he assumes all departments can be adjacent to each other.

When there are shape constraints, a graph theoretic approach using maximal stable set is developed by Dowsland [9]. She found that the problem of finding an optimal layout for a given sizes of departments and plant size is equal to that of finding a maximal stable set in the corresponding factory graph. Theoretically, her approach can find the optimal solution, but it requires much computational time.

Most of the current methods and software used for facility layout are heavily dependent on human aid. Since the problem in this paper is NP-Complete, a heuristic approach is more desirable. In Section 3, new solution approaches for the factory layout problem with aisle distance measure will be presented. When a feasible layout is obtained, the algorithm to determine the door location of each department is presented. In order to construct aisle structure with minimum aisle distance, the original layout is expanded and Floyd algorithm [11] is employed to find the shortest paths between door location. Whenever a new solution is obtained, it is compared with the best solution recorded. Continue this procedure until the stopping criterion is satisfied.

3. SOLUTION APPROACH

Given a from-to chart, we can generate a network and find a cut tree by using the Gomory and Hu method [12]. Because trees are one of the simplest graphs to understand and manipulate, analysis of trees is much easier than any other graph. A cut tree can be used in facility layout [1, 3, 13, 16] because it contains much information about original network even though it is tree structure. Since all the flows are considered to calculate the minimum cuts for the graph with only (n-1) iterations, a cut tree has information about all flows among nodes. Therefore, a cut tree can be used to aid designers in easily generating initial layouts.

For generating factory layout, two approaches, the branch and bound techniques based on eigenvector approach and cut tree approach, are employed to obtain the feasible layout. Then, the algorithm to fix the door location and Floyd algorithm [11] to find shortest paths are applied to compute the sum of aisle distance including material flow. Whenever the new feasible layout is generated, the obtained solution is compared with the best solution up to now. If the new solution is better, update the best solution. Otherwise, find another feasible solution until the stopping criterion is satisfied. The computational results of both approaches are compared with each other.

3.1 Eigenvector approach

Given a flow matrix, a scattered diagram using the eigenvector approach of Drezner [10] can be obtained by calculating the eigenvectors of modified flow matrix. The second and third largest eigenvalues are plotted on the two dimensional space (factory) and the designer shows how closely related the departments should be. Kim et al. [2] and Tillinghast [19] uses this scattered diagram within the branch and bound technique. This paper extends his method developed for the quadratic assignment model of the facility layout problem for square shaped departments to handle rectangular shaped departments.

Even though Drezner presented a scattered diagram (point layout) which provides good insight for the design analyst, he generated the final layout only when all facility sizes were equal. When the sizes and shapes of departments are fixed, the extensions we develop can be used to find final layout. The grid assignment and tree manipulation routines (see details in [2]) are be revised for this purpose. However, the procedure of finding the departments for corner location and rotation of point layout for better solution are unchanged.

3.2 Cut tree approach

Since the cut tree itself has the information of flow matrix, the shape of cut tree and maximum flow matrix are important factors for analyzing the cut tree. Since we assumed both plant shape and department shapes are squares or rectangles, there are four corner locations. If the departments for corner locations are determined, it is easy to find a feasible layout because that removes so many combinations which generate infeasible solutions.

Using the optimal layout of department centers generated by Drezner's algorithm [10], partial information about the final position of departments with respect to each other for the rectilinear distance metric can be gathered. By knowing which departments will be most likely be adjacent to each other in the final solution the search for an optimal fit can be reduced.

The branch and bound technique used to determine relationships between departments is based on the fact that the Drezner plot represents the optimal location of department centers with respect to each other. On the plot, a circle is drawn for each department. Each circle is centered at one of the departments and is expanded until it encompasses a specified number of its neighboring departments. The departments that a circle encompasses are the ones that are allowed to be adjacent to the one at the center of the circle. The number of departments encompassed is one of the input variables to the branch and bound technique. The more departments encompassed, the more computation time will be required. See details in [1].

3.3 Procedures for factory layout with aisle distance

With the rectilinear distance measure, the centroids of departments are used to calculate the distance between departments. However, when the aisle distance measure is applied, it is necessary to find the location of each department's door (input/output of material flow) between departments. Aisle distance is defined as the distance from door location to door location along aisle path between two departments.

3.3.1 Determining the door locations

It is assumed that there is only one door available for a department and the location of the door is also confined to the corner place of each department. Then, four corner locations are needed to check to minimize the aisle distance. In a feasible (complete) layout, it is desirable to cluster the doors as close as possible. This idea is compatible with the fact that larger departments should be placed around the perimeter of the facility in order to minimize material handling cost [1]. We will present a procedure to determine the door coordinates (location) of departments.

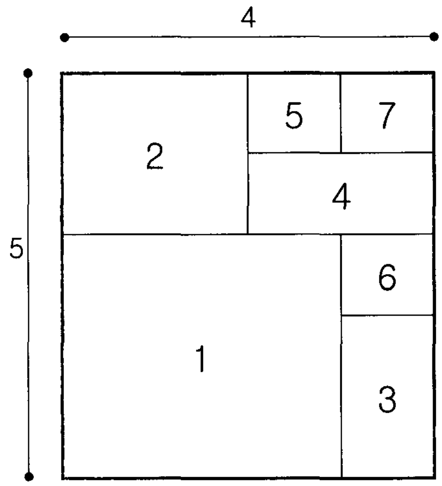
Algorithm.

Step 1. Find the centroid of plant area, say (P_x, P_y).

Step 2. Pick the center node (department) in a cut tree and compute the coordinates of four corners of that department in a feasible layout.

Step 3. Find the corner point (door location), say (d_x^c, d_y^c), with minimum distance from (P_x, P_y).

Step 4. Find the door locations for all departments which have the minimum distance from (d_x^c, d_y^c) to corner point of all departments.

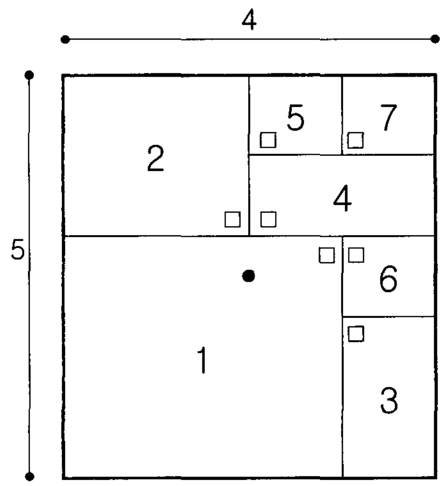


<Figure 1> Feasible layout with 7 departments and 5×4 plant area

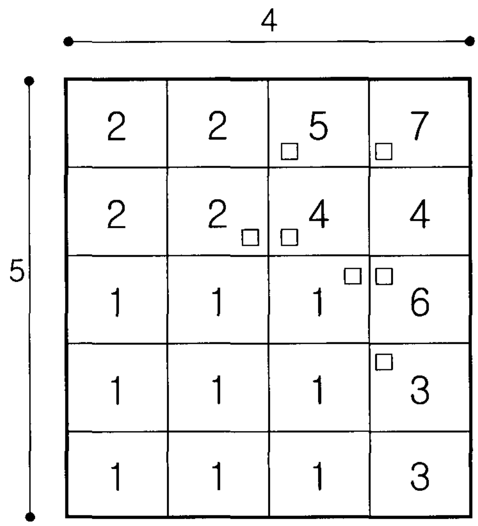
Example. Consider the layout problem with 7 departments. If we generate a feasible layout (Figure 1) and department 4 is the center node of the cut tree, the center, (P_x, P_y), of the 5×4 plant, is represented by ● mark in Figure 2. From the four corner points in department 4, we can pick the corner with □ mark because it has the minimum rectilinear distance from ● mark. Then, the door locations for any other departments can be determined by computing the distance from □ mark in department 4 to each corner. The door locations for other departments are represented by □ mark.

3.3.2 Constructing the aisle structure

If the door locations are determined, we have to construct an aisle structure for computing the aisle distance (door to door distance with aisle path). Since we assumed that an aisle cannot pass through a department, it is necessary to check the edges of departments for aisle. If the plant size is divided into grids 1×1 (unit) and expand the feasible layout to find the candidate grids for aisle, we can generate all possible aisle structures. For example, there are a feasible layout (Figure 1) and its grid layout (see Figure 3). Without loss of generality, let P_l and Pw be the length and width of plant size, respectively. Then, the original plant size $(P_l \times Pw)$ is expanded to $(2P_l\text{-}1)(2Pw\text{-}1)$ size for constructing aisle structure. Since the plant size in Figure 1 is 20 (5×4), the expanded plant size in Figure 4 is 63 (9×7), and the expanded plant layout with the door locations (*D* mark) is shown in Figure 4.



<Figure 2> Door locations for 7 departments



<Figure 3> Grid layout

7 × 9

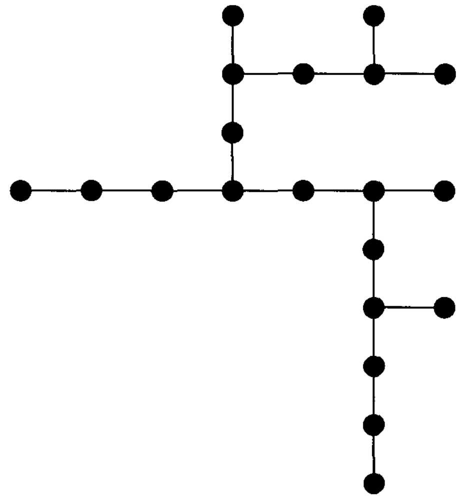
2	X	2		5		7
X	X	X	D		D	
2	X	2		4	X	4
			D		D	
1	X	1	x	1		6
X	X	X	X	X	D	
1	X	1	X	1		3
X	X	X	X	X		X
1	X	1	X	1		3

<Figure 4> Expanded layout for aisle layout

Lemma. Let li and wi be the length and width of department i, respectively. If the original plant size is $P_x \times P_y$, then the total number of grids, Ng, for aisle candidates are equal to $N_g=(2P_x-1)(2P_y-1)-P_xP_y-\sum_{i=1}^{n}[(2l_i-1)(2w_i-1)-l_iw_i]$(Proof) There are two kinds of grids disqualified for aisle in expanded layout. One is the grids disqualified because of original layout(the grids with number in Figure 4), and the other is the grids disqualified because of department size itself (the grids with × mark in Figure 4). From the number of grids in expanded layout, $(2P_x-1)(2P_y-1)$, first subtract the original plant size, P_xP_y. To find the number of grids disqualified by department size, subtract the original size of department i, l_iw_i from the number of grids for department i in expanded layout, $(2l_i-1)(2w_i-1)$. Next, all grid numbers disqualified because of department size itself is computed. Then, the desired result is obtained by subtraction it from the number of grids in expanded layout. ■

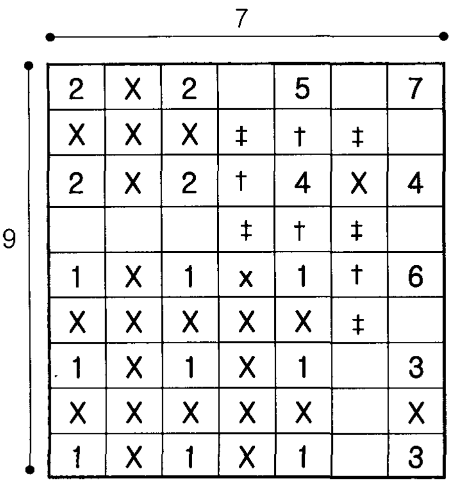
In order to obtain the aisle distance between departments, we need to compute the distance between doors. Consider the above Example. After choosing the grids for aisles in Figure 4, we can construct a network (see Figure 5) whose arc lengths are equal to one, and the total number of nodes are equal to 20. Each node in Figure 5 represents each grid qualified for aisle structure in the expanded layout.

Since finding shortest path of the network is the same as finding aisle distance, we need to find the shortest path between nodes (grids). Floyd's algorithm [11] is chosen in order to solve the problem because it provides the shortest distance as well as the associated shortest path. Let d^j_{ik} and r^j_{ik} be the distance of the shortest path from node i to node k and the first intermediate node of shortest path from node i to node k at the j^{th} iteration, respectively. Also, let c_{ik}, one, be the distance from node i to node k if both nodes are directly connected. Otherwise, $c_{ik}=\infty$.

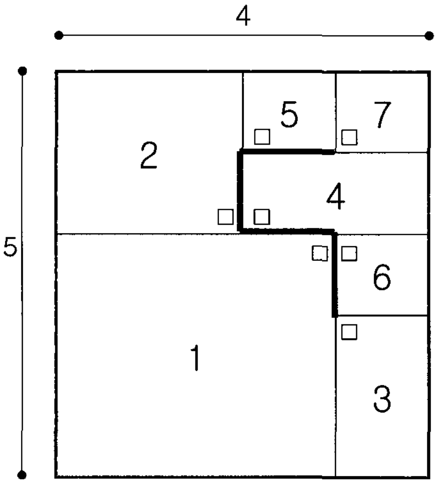


<Figure 5> Network for aisle structure

After applying Floyd's algorithm to the network (Figure 5), we can obtain the aisle structure since we know which node represents which department's door location. Then, we can calculate the aisle distance including material flow using the distance matrix, D. If the solution of the obtained factory layout is better than the best solution up to now, we need to update the best solution. In order to construct aisle structure, we also need the route matrix, R. The aisle distance between department 6 and department 7 is 6, but there are two paths which connect both department's doors with aisle distance 6 (see Figure 6). In this case, we choose the path which passes more door locations. That reduces the space for material handling system in the factory. The aisle structure of the layout (Figure 4) is presented in Figure 6. The grids for door locations and aisles are denoted by ‡ and † marks, respectively. Finally, the expanded layout is reduced to original size with aisle structure and it is shown in Figure 7. After satisfying the stopping criterion of the proposed branch and bound technique, the final factory layout will be obtained. The architect or plant designer will determine the final factory layout based on the obtained layout considering practical situations and constraints.



<Figure 6> Aisle structure for expanded plant



<Figure 7> Factory layout with aisle structure

3.4 Computational results

We generated 27 test problems in order to obtain the factory layout considering flow with the aisle distance measure. They can be divided into three subproblems concerning flow dominance : flow matrix with low flow dominance, flow matrix with medium flow dominance and flow matrix with high flow dominance. Both distance criterion and size criterion are considered for corner position and neighborhood set in the branch and bound technique. In the test problems with an aisle distance measure, the method that the size criterion is the first choice for corners performs better than the method that the distance criterion is the first choice for corners because the aisle can pass only the edge of the departments. This paper focuses on the first attempt to obtain good factory layout considering the determination of door location, construction of aisle structure and dimension constraints, simultaneously. Since there is no literature which provides the factory layout with aisle distance after determining the door locations and aisle structure, we just provide the results in Table 1.

<Table 1> Solutions with aisle distance

test°	solution	test†	solution	test*	solution
pb lm.	(-, -, -)[a]	pb lm.	(-, -)[a]	pb lm.	(-, -)[a]
1[d]	(2294,1386,1230)	10[d]	(3962,3636,2176)	19[d]	(5318,5528,4264)
2[c]	(2742,1898,2026)	11[d]	(4056,3204,2740)	20[d]	(5746,4983,4046)
3[d]	(3232,1716,1358)	12[d]	(3808,3448,2508)	21[d]	(5852,5308,4114)
4[d]	(3210,2904,2120)	13[d]	(4897,4245,3382)	22[d]	(6480,8193,5511)
5[d]	(3060,2686,1580)	14[d]	(4470,5554,3254)	23[d]	(6436,7346,4930)
6[d]	(2602,3636,1791)	15[d]	(4777,4668,3290)	24[d]	(5431,7622,5051)
7[c]	(3298,2625,3396)	16[b]	(5498,9502,6112)	25[d]	(10160,14248,8280)
8[d]	(5400,4073,4265)	17[d]	(6891,9807,5094)	26[d]	(9745,13482,7122)
9[b]	(3559,3673,***)	18[d]	(7233,9471,7201)	27[d]	(10425,11279,7679)

a : best solution of (eigenvector, distance, size) criterion is chosen first
b : eigenvector approach provide best solution
c : node-arc distance criterion (cut tree approach) provide best solution
d : size criterion (cut tree approach) provide best solution
o : matrix with 70% zero and 30% nonzero elements in the range [10,100] (high)
† : matrix with 50% zero and 50% nonzero elements in the range [30,80] (medium)
* : matrix with 30% zero and 70% nonzero elements in the range [50,60] (low)

From the experiment, it is known that the size criterion is better than the distance criterion when minimizing the aisle distance. As the flow dominance becomes lower, it works better since the cut tree shape becomes more of a daisy shape. Also, the eigenvector approach very frequently generates the worst solution because the cut tree approach has a strong background (optimal linear ordering [5]) for aisle distance. If we want to minimize the aisle distance, usually the cut tree approach is desirable.

We generated 9 test problems for a two floor building and 9 test problems for a three floor building. We solved the 18 test problems by the eigenvector approach and cut tree approach for a particular floor fit preserving dimensional shape (see details in [10]). After grouping departments according to the number of floors, in order to compare the eigenvector approach with the cut tree approach, we rotated the point layout three times. Both approaches limit the number of department candidates for corner location to five. The location of the elevator, waiting time and moving time for the elevator are given by users. When the distance measure is aisle, Table 2 and 3 show the results of two floor layout and three floor layout, respectively.

<Table 2> Computational results (aisle distance and two floors)

test problem	floor number	cut tree (-, -)a	eigenvector(-)b
1[c]	1 2	(2318, 2778) (3772, 4142)	(4581) (7243)
2[c]	1 2	(***, 1128) (14441, 13743)	(***)
3	1 2	(2785, 2602) (***, ***)	(3906) (***)
4	1 2	(***, ***, ***)	(***, ***, ***)
5	1 2	(12301, 8510) (***, ***)	(14197) (***)
6[c]	1 2	(6273, 5810) (30191, ***)	(7791) (***)
7[c]	1 2	(4131, 3176) (17089, 17089)	(4732) (20330)
8[c]	1 2	(***, 3238) (19116, 13895)	(7959) (27676)
9[c]	1 2	(5721, 4632) (10900, 10679)	(7959) (15679)

a : best solution of (node-arc distance, size) criteria
b : best solution without rotation
c : cut tree approach provides better solution
d : eigenvector approach provides better solution
*** : no feasible fit found

From the computational results, the cut tree approach performs better than the eigenvector approach in the aisle distance measure. Even though the eigenvector approach generates a better layout than the cut tree approach in a two dimensional layout (first floor), it provides a worse solution because of the vertical movements.

Another reason that the cut tree approach performs better than the eigenvector approach is that we grouped the departments using the information of the cut tree. As the number of floors increase, the cut tree approach provides a better solution since there are more vertical movements among floors. For the three dimensional layout problem, both approaches should be applied because of the vertical movements, especially when the number of elevator locations is less than four. The cut tree models aisle structure considering both total flow and distance better than cluster approaches [18]. The arc between nodes on different floors directly represents the flow of the elevator.

<Table 3> Computational results (aisle distance and three floors)

test problem	floor number	cut tree (-, -)a	eigenvector(-)b
1[c]	1 2 3	(1860, 1824) (4493, 5529) (49717, 49717)	(3277) (8075) (59730)
2[d]	1 2 3	(2268, 2181) (17841, 18297) (37124, 36382)	(3277) (15671) (34128)
3[c]	1 2 3	(2380, 1824) (2940, 2966) (32421, 32421)	(3828) (6153) (32874)
4[c]	1 2 3	(2708, 2624) (11142, 16593) (43790, 43790)	(2812) (16649) (44714)
5	1 2 3	(4572, 4572) (***, ***)	(6742) (***)
6	1 2 3	(3214, 2906) (46660, 45245) (***, ***)	(3742) (45779) (***)
7[d]	1 2 3	(***, 5472) (23129, 24466) (61960, 61960)	(6650) (22975) (61876)
8[c]	1 2 3	(6182, 5861) (28461, 21506) (60449, 58246)	(6853) (20420) (69836)
9[c]	1 2 3	(12809, 14609) (22992, 22762) (60911, 60911)	(15538) (25714) (67703)

a : best solution of (node-arc distance, size) criteria
b : best solution without rotation
c : cut tree approach provides better solution
d : eigenvector approach provides better solution
*** : no feasible fit found

4. CONCLUSIONS AND FURTHER RESEARCH

This paper addressed the problem of assigning n departments without shape distortion in the factory considering determination of door locations and aisle distance measure. It is the first attempt to obtain good factory layout considering the determination of door location, construction of aisle structure and dimension constraints, simultaneously. The eigenvector approach and the cut tree approach are employed in order to obtain a feasible layout. A branch and bound computer code developed by Kim et al. [2] was modified to handle to the departments with rectangle shape.

For the aisle distance measure, first we fixed the door location of each department using the information of the cut tree. Then, we expanded the complete feasible layout and find grids for aisle structure. After constructing a network which represented the possible aisle structure, we found the shortest path and the distance of the network for the aisle structure. In order to evaluate the factory layout with aisle distance, the branch and bound techniques based on both eigenvector approach and cut tree approach are employed. Since the cut tree approach has the strong background for aisle distance measure, it is shown more effective. Therefore, the cut tree approach is recommended when the aisle distance measure is considered. According to our computational results, the cut tree approach performs better than the eigenvector approach.

The system for the facility layout considering the determination of door locations, aisle structure and dimension constraints developed in this paper works when the total sum of the department area is equal to the plant area. Sometimes, it is difficult to obtain a feasible solution even though the total sum of department area is equal to the plant area without allowing th shape distortion. Suppose that the plant size is 100 (10×10) and there are two departments whose required sizes are 64 (8×8) and 36 (6×6), respectively, In this case, it is impossible to obtain a feasible solution. Further research for the layout problem without shape distortion will be in how to resolve this type of problem.

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